

matic, electromechanical, or other components at larger distances above and/or below the liquid module.

[0202] When compressing a fluid vessel, or blister, to displace the fluid contents thereof, sufficient compressive force must be applied to the blister to break, or otherwise open, a breakable seal that is holding the fluid within the vessel. The amount of force required to break the seal and displace the fluid contents of a vessel typically increases as the volume of the vessel increases. This is illustrated in the bar graph shown in FIG. 11, which shows the minimum, maximum, and average blister burst forces required for blisters having volumes of 100, 200, 400, and 3000 microliters. The average force required to burst a blister of 400 or less microliters is relatively small, ranging from an average of 10.7 lbf to 11.5 lbf. On the other hand, the force required to burst a blister of 3000 microliters is substantially larger, with an average burst force of 43.4 lbf and a maximum required burst force of greater than 65 lbf. Generating such large forces can be difficult, especially in low profile actuator mechanisms, such as those described above, in which horizontal displacement of an actuator is converted into vertical, blister-compressing movement of a platen.

[0203] Accordingly, aspects of the present invention are embodied in methods and apparatus for opening a fluid vessel, or blister, in a manner that reduces the amount of force required to burst the vessel and displace the fluid contents of the vessel.

[0204] Such aspects of the invention are illustrated in FIGS. 8A and 8B. As shown in FIG. 8A, a fluid vessel (or blister) 122 is mounted on a substrate 124 and is connected by means of a channel 130 to a sphere blister 128. In certain embodiments, channel 130 may be initially blocked by a breakable seal. A film layer 129 may be disposed on the bottom of the substrate 124 to cover one or more channels formed in the bottom of the substrate 124 to form fluid conduits. An opening device, comprising a sphere 126 (e.g., a steel ball bearing) is enclosed within the sphere blister 128 and is supported, as shown in FIG. 8A, within the sphere blister 128 by a foil partition or septum 125. The foil partition 125 prevents fluid from flowing from the vessel 122 through a recess 127 and fluid exit port 123. Upon applying downward force to the sphere 126, however, a large local compressive stress is generated due to the relatively small surface size of the sphere 126, and the foil partition 125 can be broken with relatively little force to push the sphere 126 through the partition 125 and into the recess 127, as shown in FIG. 8B. With the foil partition 125 broken, a relatively small additional force is required to break a seal within channel 130 and force the fluid to flow from the vessel 122 through the fluid exit port 123.

[0205] In FIG. 8B, the sphere blister 128 is shown intact. In some embodiments, a force applied to the sphere 126 to push it through the foil partition 125 would also collapse the sphere blister 128.

[0206] An apparatus for opening a vessel by pushing a sphere 126 through foil partition 125 is indicated by reference number 120 in FIGS. 9A, 9B, 9C, 9D. In the illustrated embodiment, the apparatus 120 includes a ball actuator 140 extending through an opening formed through a blister plate, or platen, 132. With the blister plate 132 and an actuator 138 configured for moving the blister plate 132 disposed above the vessel 122, the ball actuator 140 is secured in a first position, shown in FIG. 9A, by a detent 136 that engages a detent collar 144 formed in the ball actuator 140.

[0207] As shown in FIG. 9B, the blister plate 132 is moved by the actuator 138 down to a position in which a contact end 142 of the ball actuator 140 contacts the top of the sphere blister 128. Actuator 138 may comprise a low profile actuator, such as actuator mechanisms 50 or 80 described above.

[0208] As shown in FIG. 9C, continued downward movement of the blister plate 132 by the actuator 138 causes the ball actuator 140 to collapse the sphere blister 128, thereby pushing the opening device, e.g., sphere 126, through a partition blocking fluid flow from the vessel 122. In this regard, it will be appreciated that the detent must provide a holding force sufficient to prevent the ball actuator 140 from sliding relative to the blister plate 132 until after the sphere 126 has pierced the partition. Thus, the detent must provide a holding force sufficient to collapse the sphere blister 128 and push the sphere 126 through a partition.

[0209] As shown in FIG. 9D, continued downward movement of the blister plate 132 by the actuator 138 eventually overcomes the holding force provided by the detent 136, and the ball actuator 140 is then released to move relative to the blister plate 132, so that the blister plate can continue to move down and collapse the vessel 122.

[0210] After the vessel 122 is collapsed, the blister plate 132 can be raised by the actuator 138 to the position shown in FIG. 9A. As the blister plate 132 is being raised from the position shown in FIG. 9D to the position shown in 9A, a hard stop 146 contacts a top end of the ball actuator 140 to prevent its continued upward movement, thereby sliding the ball actuator 140 relative to the blister plate 132 until the detent 136 contacts the detent collar 144 to reset the ball actuator 140.

[0211] An alternative embodiment of an apparatus for opening a vessel embodying aspects of the present invention is indicated by reference number 150 in FIG. 10. Apparatus 150 includes a pivoting ball actuator 152 configured to pivot about a pivot pin 154. A top surface 156 of the pivoting ball actuator 152 comprises a cam surface, and a cam follower 158, comprising a roller, moving in the direction "A" along the cam surface 156 pivots the actuator 152 down in the direction "B" to collapse the sphere blister 128 and force the sphere 126 through the foil partition 125. Pivoting actuator 152 may further include a torsional spring (not shown) or other means for restoring the actuator to an up position disengaged with the sphere blister 128 when the cam follower 158 is withdrawn.

[0212] FIG. 12 is a plot of compressive load versus time showing an exemplary load versus time curve for an apparatus for opening a vessel embodying aspects of the present invention. As the apparatus contacts and begins to compress the sphere blister 128, the load experiences an initial increase as shown at portion (a) of the graph. A plateau shown at portion (b) of the graph occurs after the sphere 126 penetrates the foil partition 125. A second increase in the force load occurs when the blister plate 132 makes contact with and begins compressing the vessel 122. A peak, as shown at part (c) of the plot, is reached as a breakable seal within channel 130 between the vessel 122 and the sphere blister 128 is broken. After the seal has been broken, the pressure drops dramatically, as shown at part (d) of the plot, as the vessel 122 is collapsed and the fluid contained therein is forced through the exit port 123 (See FIGS. 8A, 8B) supporting the sphere 126.